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Multiscale analysis of hillslope height for geomorphometry

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1. Introduction

Geomorphometry aims to quantitatively characterise the form of surface relief and is an important component of geomorphological research. As the availability of digital data describing topography has increased in terms of both the extent of the Earth's surface characterised by such data and their resolution, so has the use of computational techniques attempting to automatically extract information describing landforms increased.

These computational techniques focus on the use of regular grids of elevation and often use standard techniques to either derive indices with a direct geomorphological meaning (e.g. slope and curvature) or to identify particular features within a landscape (e.g. peaks and passes). Within the GIScience community it is well recognised such analysis is strongly scale dependent, and thus that a particular location may be described differently as measurement scale varies. Thus, for example Fisher et al. (2004) extract features from terrain models at multiple scales and assign locations a fuzzy membership of some feature class. Schmidt and Andrew (2005) argue that despite this broad understanding, “scale issues are poorly recognised and incorporated in current research and applications of terrain analysis”.

In general, scale is treated within most applications as a variable dependent on some given sampling window size at a location, where the minimum horizontal length scale at which analysis can be performed is by definition twice the DEM resolution. In practice, sampling windows are generally centred on the cell of interest, thus sampling windows consider $(2^n+1) \times (2^n+1)$ cells where n is an integer. Such approaches clearly show how properties of location can vary with sampling scale, but ignore potential analysis scales inherent in the landscape itself. For example, geomorphologists might be interested in the variation of some parameter across individual hillslopes, drainage divides or mountain belts, where the division between such units is not related to a fixed horizontal length scale.

In this paper we report on the development of a tool for terrain analysis that allows the hierarchical division of 1D profiles according to some terrain-based definition of scale. We apply this method to the extraction of measures of hillslope height, which determines potential energy along valley flanks, thus being a first-order control on most geomorphic processes. Together with local relief, hillslope height is a measure of potential release of

topographic stress following processes of crustal unloading, and sets the boundary conditions for numerous surface processes.

The key problem is that measures of both local relief and hillslope height are commonly derived using a fixed horizontal length scale (Ahnert, 1984; Montgomery and Greenberg, 2000). This does not take into account the variability in topographic wavelength set mainly by geology and drainage density. Thus, such measures implicitly rely on a large enough sampling radius to sufficiently capture the full, or at least characteristic, bandwidth of local relief within a given area. This depends in turn on the scale of the landform to be investigated.

We introduce our method for defining scale within a profile, before applying it to the extraction of hillslope height and compare values derived on the basis of a fixed horizontal length scale. Finally, we briefly discuss the implications of these preliminary results.

2. Methodology

Our aim was to develop a method which could be applied easily to large numbers of 1D profiles of elevation, for example derived across a mountain belt, in order to qualitatively and quantitatively describe such profiles and derive populations on which statistical tests could be performed. The use of such profiles is still commonplace in geomorphology, but analysis techniques remain relatively simple.

Given a profile with values (z_1, z_2, \dots, z_n) then this profile can be hierarchically subdivided into a set of sub-profiles based on some given criteria. Any parameter that can be derived for the initial profile can also be calculated for a given sub-profile, as long as the profile length is longer than the horizontal length scale required to calculate the parameter.

We define hillslope height at a given point on a profile as its height above the valley floor, that is

$$hs_i = z_i - \min(z_k, k \in \{a, \dots, b\})$$

where hs_i is the hillslope height of element i

z_i is the elevation of element i

and z_k is height of element k in the profile lying between elements a and b .

The maximum value of hillslope height is therefore the difference between the maximum and minimum elevation in a profile. Thus, the first possible subdivision of a profile is located at the peak within the profile which has the highest value of elevation of any local maximum within the profile. Hillslope height is then calculated with respect to the global minima to the left and right of this local maximum.

Since profiles consist of discrete elevation values, local maxima are defined as points where $z_{i-1} < z_i > z_{i+1}$. If $z_{i-1} = z_i$ or $z_i = z_{i+1}$ then the condition is extended leftwards or rightwards in the profile respectively. Furthermore, profiles are smoothed before

searching for local maxima to minimise the number of spurious peaks identified within the profile.

We calculated local relief at different scales as a function of varying window sizes, where the local relief was defined as the difference between the maximum and minimum values of elevation within the sampling window. Slope was defined as the magnitude of the first derivative of elevation, calculated by a centred finite difference scheme.

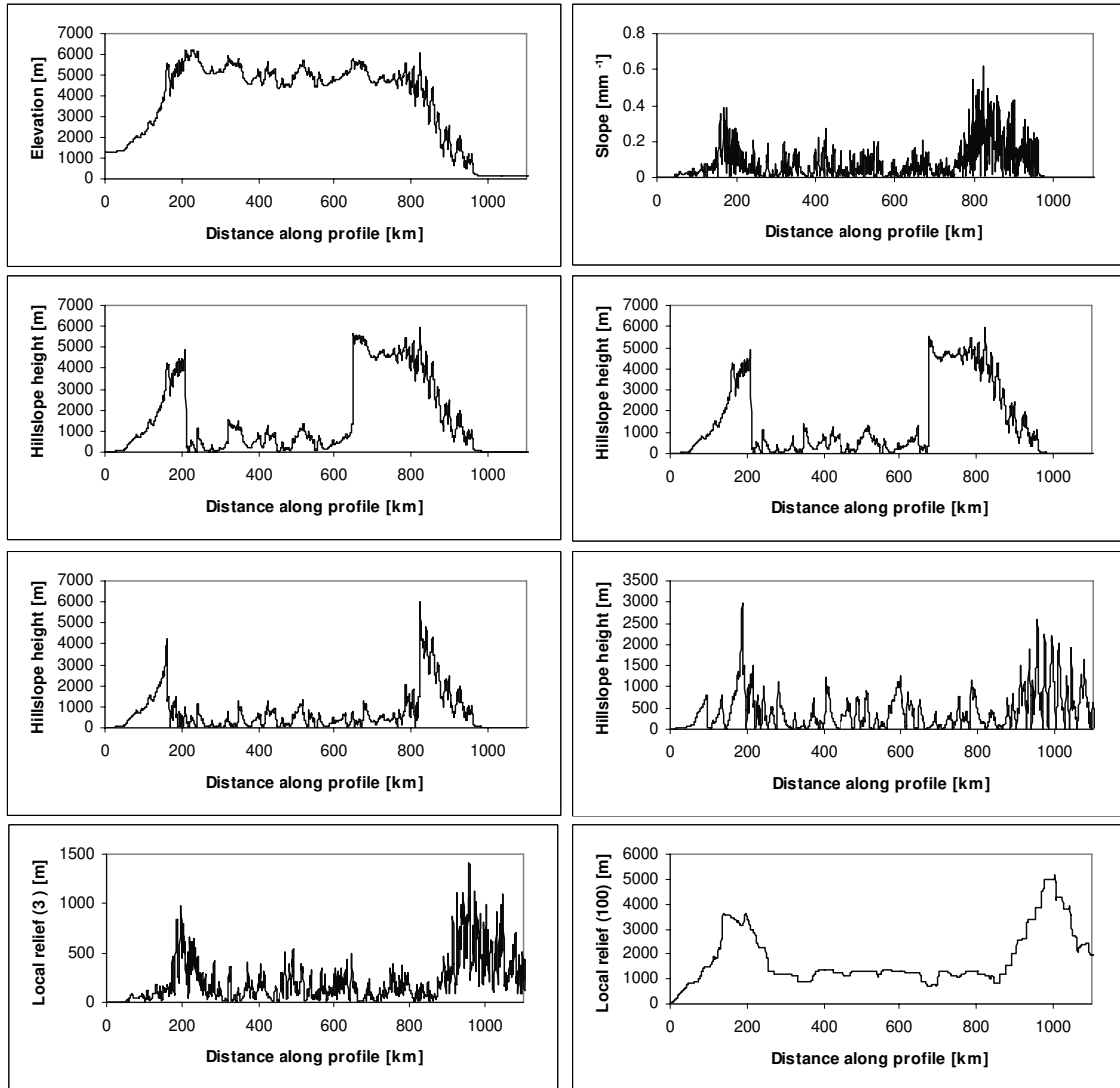


Figure 1: Elevation, slope, hillslope height and local relief profiles. Hillslope heights for profiles defined by the highest 5, 10, 20 and 45 peaks respectively. Local relief for a 3 cell and 101 cell window

3. Results

Results for a range of parameters (elevation, gradient, hillslope height, local relief) are illustrated here for a profile derived in a north-south direction from the Tarim Basin across the Tibetan Plateau and Himalayas to the Bengal foreland (Figure 1), at a

resolution of ~860m. The profile was selected to lie perpendicular to the main mountain belt. The variation of hillslope height with the number of peaks used as a reference highlights the hierarchy of the terrain, dominated by two high-relief mountain belts flanking a low-relief high plateau. Despite a similar regional pattern, local hillslope height for 45 peaks does not correlate well with mean local relief derived from a moving window with a fixed sampling radius (Table 1).

	Elevation	Slope	Hillslope height (5)	Hillslope height (10)	Hillslope height (20)	Hillslope height (45)	Local relief (3)	Local relief (101)
Elevation	1.00	0.21	0.41	0.34	0.12	0.28	0.23	0.20
Slope		1.00	0.44	0.46	0.55	0.53	0.92	0.64
Hillslope height (5)			1.00	0.90	0.45	0.47	0.48	0.48
Hillslope height (10)				1.00	0.51	0.52	0.51	0.53
Hillslope height (20)					1.00	0.78	0.61	0.81
Hillslope height (45)						1.00	0.58	0.61
Local relief (3)							1.00	0.71
Local relief (101)								1.00

Table 1: Pearson correlations (r) for series shown in Figure 1

4. Discussion

Scale is *the* crucial issue in topographic analysis. We suggest that our method provides a more detailed and hierarchically structured, yet objective, view of topography than is possible from applying commonplace moving-window approaches. This is chiefly because the method quantifies relief as a nested function of local elevation maxima in the terrain. Thus, this method of detection is not susceptible to the averaging effects that are clearly visible in the local relief values calculated for large window sizes as shown in Figure 1.

There are several geomorphologic applications in this regard, as the method conserves information on both the horizontal and vertical pattern of topography. Hence, the length scale of landforms can be delineated and measured. For instance, the width of the Tibetan plateau can be readily extracted as the horizontal distance between the two points with the highest hillslope height along the profile in Figure 1. Using repeat measurements along parallel profile lines could thus aid regional-scale landform delineation.

In the vertical dimension, values of hillslope height derived for low values in the peak ordering provide values of the absolute relief of the Tibetan plateau. Comparable values are not usually given by other methods, as they are limited to (local) variations of a fixed length scale only. Thus, the method allows objective detection of the position and size of the deepest valleys, i.e. where local hillslope height is at a maximum.

However, it is important to note that in order to be geomorphologically meaningful, our method still requires qualitative interpretation based on knowledge of the landscape and,

ideally, comparison with additional data on processes that contributed to shape the landscape in question.

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Biography

Ross Purves is a lecturer in GIScience at the University of Zurich.